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INVESTIGATING RESILIENT ROMAN AGRICULTURAL LANDSCAPES IN SOUTHERN ITALY. AN INTEGRATED AND OPEN IT APPROACH TO MODELING CENTURIATION

1. Introduction

The Investigating Resilient Roman Agricultural Landscapes in Southern Italy (IN.RES.AGRI) project, funded by the Italian Government (PRIN 2022, project code 2022SMJCHX) is concerned with the analysis of the long-standing persistence and discontinuities of Roman rural topography, in order to understand how its components have survived throughout centuries embedded in the contemporary landscapes of Southern Italy. The rational management of space – above all for land reclamation to improve agricultural yield – is likely the main reason for the survival of the centuriated topography. However, this is not the only reason, especially in contexts that have maintained their rural vocation, as in Puglia, or that have undergone strong urbanization processes, as the suburbs of Naples. The Archaeological Mapping Lab of the University of Naples, together with the Labs of the Istituto di Scienze del Patrimonio Culturale (ISPC) of the CNR and the University of Salento, aim at optimizing our knowledge on Roman agricultural landscapes in Southern Italy through a holistic approach, integrating topographical, archaeological, environmental and textual data within an innovative data-science platform named Digital_Groma.

Resilience of Roman agrarian landscapes will be inspected based on a set of aspects, such as *centuriatio*, routes network and settlement patterns systems (Castagnoli 1958; Settis 1993). The project will focus on the systematic collection of legacy data (topographical, archaeological and textual data) and new evidence from the field in selected case study areas in Campania and Puglia (Fig. 1). Data regarding those case studies will populate an IT infrastructure able to inspect and visualize the relations linking contemporary landscapes and Roman agro-ecosystems through millennia.

R.B., V.F., I.R.

2. New methods for old questions

The In.Res.Agri project aims at enhancing the knowledge on Roman agrarian landscapes in Southern Italy through an interdisciplinary, holistic approach integrating archaeological, geospatial, environmental and textual data. Therefore, the overview of the state of the art should necessarily consider a dual perspective, which can be summarized by the definition:

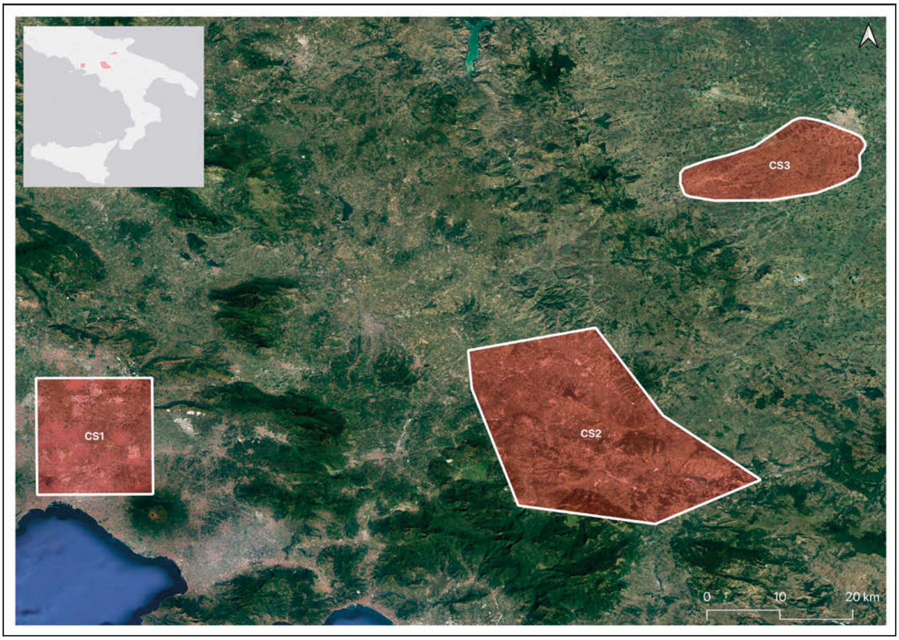

Fig. 1 – Distribution map of the case studies in the context of Southern Italy.

'archaeogeography' (Roberts 2011; Brigand 2015). From a topographical point of view, the interest in centuriated Roman landscapes and related literary sources highly increased during the 20th century (Castagnoli 1958). In the following decades, the archaeological analysis of centuriations has been centred on the identification of traces present in the modern landscape that could morphologically refer to Roman times (Muzzioli 2009). During the 1980s, the Besançon Group developed a series of techniques aimed at identifying centuriated grid systems by their orientation and by the proportions of *centuriae* with modules based on multiples of the Roman actus (Clavel-Lévêque 1983; Chouquer *et al.* 1987).

These systems were mainly identified in the modern landscape by carto- and photointerpretation (Guaitoli 2003). Although this approach, developed among Italian and French researchers, helped in identifying centuriations in France, Italy and other Mediterranean regions (Dall'Aglio, Rosada 2009), in some cases the hypotheses have proven to be controversial (Orengo, Martinez 2009), to be based on misunderstood finds (Liverani 1987), or to be the result of agrarian divisions of the modern or contemporary age (Brancato 2019). The failure to identify centuriated systems with certainty has sometimes resulted in the dismissal of photo-interpretation: this is due to the lack of a consistent and interdisciplinary methodology; indeed, a solely topographical identification of centuriated field systems is an incomplete procedure which can lead to a continued dismissal of the discipline if not supported by the integrated use of geoarchaeology and data science (Dall'Aglio, Campagnoli 1997; Dall'Aglio 2009), as well as by analysis of territory's physical geography and its changes over time (Quilici Gigli 1997).

The current availability of remotely sensed images makes it urgent to develop automatic methods that can simplify their inspection and extraction, as the quantity of information is no longer manageable by traditional 'human' visual interpretation (Traviglia, Torsello 2017). The project's aim of deepening the knowledge on resilient centuriation grids and their relationship with contemporary landscapes fits perfectly with the innovative research approaches grounded on the development of cutting-edge computer methods and techniques applied to archaeological spatial research (Brancato 2019), for the understanding of the impact of the centuriation engineering projects on the environment and the reason for their persistence in the historical landscape. Today, landscape archaeology – or archaeogeography as some specialists prefer to call it (Chouquer 2008) – increasingly benefits from aerial and satellite remote-sensing techniques and spatial data-science analytical tools, to suggest new socio-dynamic configurations of ancient land organization.

In this, landscape archaeology finds support in geospatial information and GIS systems, which improve the integration of data acquisition, representation, and analysis activities in a virtual environment allowing archaeologists to centralise traditional investigation procedures, such as field surveys and lab data processing (Moscati 2017). The In.Res.Agri project is pioneering in combining new methods of topographic research, in which Artificial Intelligence and Machine Learning algorithms play an important heuristic role (Lambers *et al.* 2019; Olivier, Verschoof-van der Vaart 2021), with the Open Science paradigm, which – in accordance with the EU's Open Science policy – fosters the implementation of services and tools to facilitate interoperability between open digital repositories (see, e.g., the European Open Science - EOSC portal; https://eosc-portal.eu/).

The history of automated archaeological object detection in remotely sensed data and automated map analysis is recent, but progress is already evident in the shift towards Machine Learning methods. The goal of collecting, managing and preserving rich digital contents in the long term, in open access environments, mainly refers to large integrated datasets recorded over a long period of time and now stored in *ad hoc* digital repositories (Richards *et al.* 2021). By adopting this approach, tailored on a smaller scale, a well-established procedure will be followed, which envisages the merging of diversified resources, to be structured and tagged with metadata, with the aim of freeing up and sharing their scientific contents (Rossi, Paraciani 2021).

3. Project's aims and case studies

Based on these premises, the project specifically aims at: 1) creating a model that will define the Roman centuriation methods, theory and practice through a detailed analysis of topographic, geomatic, archaeological, environmental, iconographic and textual data in a specific geographical horizon (i.e. the Southern Italy corridor that goes from Campania to Puglia) and in a coherent chronological context (i.e. the Roman age); 2) interpreting the transformations implied by a rational land division and distribution, as is the case of those occurred in Roman Southern Italy, through a diachronic definition of how geomorphology, pre-existing routes network, and land reclamations interacted in the process of making Roman centuriation a highly resilient landscape element. Indeed, archaeological research in Italy has created a massive amount of data (archaeological maps) fundamental for interpreting, in light of anthropic and non-anthropic taphonomic processes (Jackson, Moore 2018), the relationship between centuriations and other landscape elements such as the roads system; 3) testing the integration of traditional survey methods and innovative technologies for the recovery, interpretation and restitution of topographical data; 4) contributing to the implementation of the Open Science paradigm, by making project data accessible for fruition by a larger public and available for reuse. Within the project, three selected areas where previous research highlighted the existence of centuriation will be used as case studies, with particular emphasis on the chronological phase going from 500 BC to 500 AD.

3.1 *The central Campana Plain area*

As regards the first case study, the research will focus on a crucial sector of the Campania region, specifically the central-southern area of the Campanian alluvial plain where Atella was located (Di Vito *et al.* 2021, with references) (Fig. 2). This town, S of the Clanio river on the road connecting Neapolis and Capua, was surrounded by a rich agricultural territory. As highlighted by Stefania Quilici Gigli, it is necessary to consider the relationship between the cadastral system of Atella's territory (Bencivenga Trillmich 1984) and the *ager Campanus*, whose centuriation system is widely recognized by scholars (Quilici Gigli 2002, with references). As regard the *ager Atellanus*, its grid was identified in aerial imagery, together with the presumed centuriations of Acerra and Neapolis in 1987, and dated to the Augustan age due to module and orientation solely based on cartographic observation (Choquer *et al.* 1987). The recognition of the centuriation limits of the *ager Campanus*'s south-eastern portion – today belonging to the territory of Succivo and Orta di Atella – is still largely unsolved (Soricelli 2001; Monaco 2004; Monaco, Clavel-Lévêque 2004).

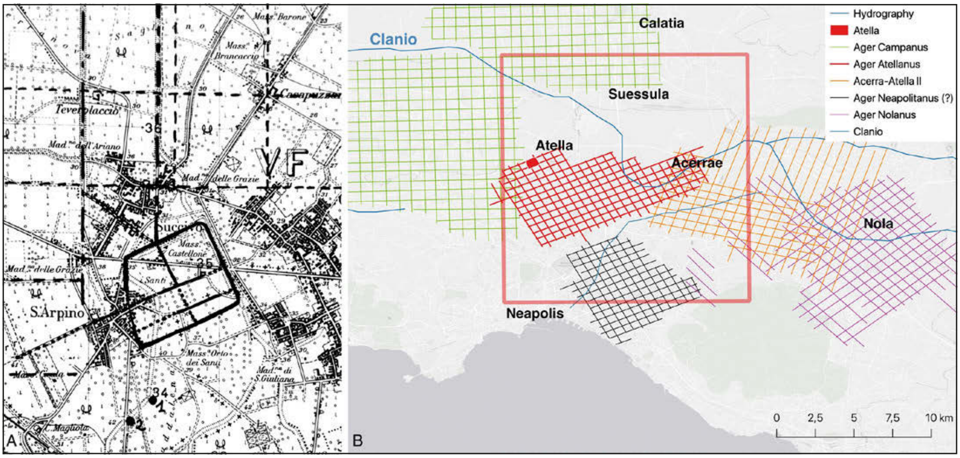

Fig. 2 – The site of Atella and its hypothesized cadastral layout (case study 1) plotted on a 1:25,000 scale topographic map (A) and within the broader context of Campania region (B).

Although it is certain that the main axis of the centuriation was linked to the urban plan of Atella, here located, little is known about the urban plan of the Roman *municipium* and the agrarian division of this sector of the plain. Traces detected in historical cartography and aerial photos point to the alleged existence, never verified on the field, of different superimposed agrarian systems, i.e. 'Acerrae-Atella I' (Choquer *et al.* 1987, 207, fig. 70; 226- 227, 252) and 'Atella II' (Choquer *et al.* 1987, 208-209, fig. 71, 228-229), whose topography is not consistent with that of the *ager Campanus*. Morevore, the cadastral system labelled as 'Acerrae-Atella I' was dated to the Augustan age only for its module and orientation (Chouquer *et al.* 1987); recently its dating has been antedated to the second century BC (Giampaola 1997, 232), based on excavations carried out on sections of canals and roads. However, we also know that the whole centuriation system was covered by the volcanic ash of the AD 79 eruption; since then, Vesuvius erupted approximately 36 times (De Vito *et al.* 2021).

Here preventive archaeological excavations have frequently uncovered plowed fields and roads sealed by the eruption of Pollena in 472 AD and still consistent with the cadastral system. Hence, to understand why the topography of ancient rural and urban landscapes has survived through centuries, as is clearly visible in remotely sensed data, i.e. historical aerial photographs and LiDAR digital elevation model, it is crucial to consider the adaptive strategies put into practice by local communities and their political institutions (Fig. 3). On the other hand, it is also time to verify the archaeological consistency of the cadastral systems hypothesized by previous research. To reach this goal,

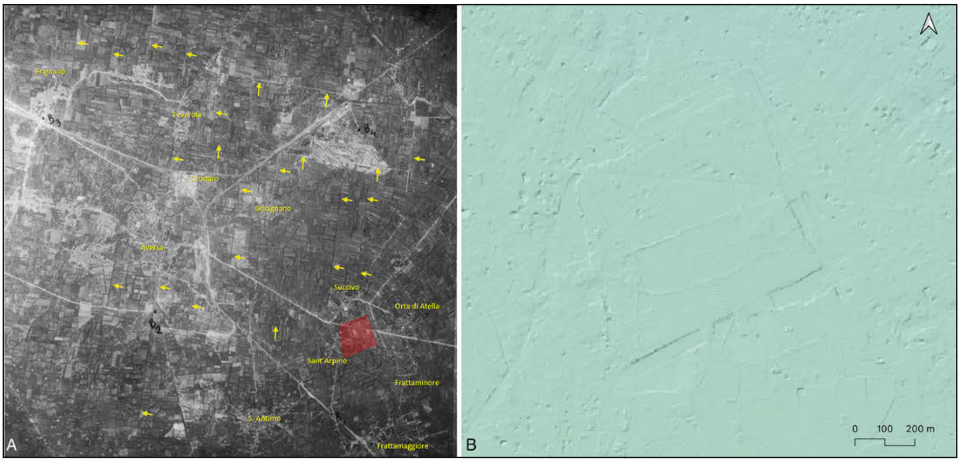

Fig. 3 – Atella and its territory (case study 1) as seen in a historical aerial photograph (RAF 1945) annotated by G. Scardozzi (A) and in the DTM with a 1-meter ground resolution derived from LiDAR scanning acquired by the Ministry of the Environment of Italy.

the In.Res.Agri project started with the digitization process of legacy archaeological data stored in archives (Brancato *et al*. in press), and will continue with field surveys (Brancato *et al*. 2023) and targeted excavations in urban and extra-urban selected areas.

R.B.

3.2 *Irpinia*

The second case study concerns a sector of eastern Irpinia (province of Avellino), which includes the territories pertaining to the colony of *Aeclanum*, to the N, and to the municipality of *Compsa*, to the S (Fig. 4). The gromatic texts reserve precise indications regarding land divisions carried out in the *ager* of *Aeclanum* (Lib. Col. I, 210, 4-6 L; II, 261, 5-8 L) and in that of *Compsa* (Lib. Col. I, 210, 7 L; II, 261, 1 L). The discovery of some stones of land division (CIL IX, 1024, 1025, 1026; Buonopane 2013; Camodeca 2021) opened the question of the existence of an ancient land division in this territory and its dating (Gallo 2015). To date, only a recent study (Ditaranto 2017) tried to identify in the current landscape traces and alignments referable to the survival of ancient land divisions. This study, based on the analysis of historical cartography and historical aerial photographs, showed, as regards the *ager Compsinus*, a lot of alignments, identified in approx. 150,000 hectares.

Moreover, for the nearby area of *Aeclanum*, alignments compatible with a regular land division have been identified for approx. 152,000 hectares. The use of high-resolution satellite images, suitably processed, and a specific machine learning algorithm, could enrich the information already acquired and allow to formulate new hypotheses regarding the extension and orientation of the possible land divisions implemented between the Gracchan and Imperial Roman ages. Field surveys will be conducted to verify the new tracks identified.

I.D.

3.3 *Tavoliere*

In northern Apulia, between Troia (*Aecae*) to the E and Foggia to the W, the Celone stream to the N and Cervaro to the S, an extensive Roman land

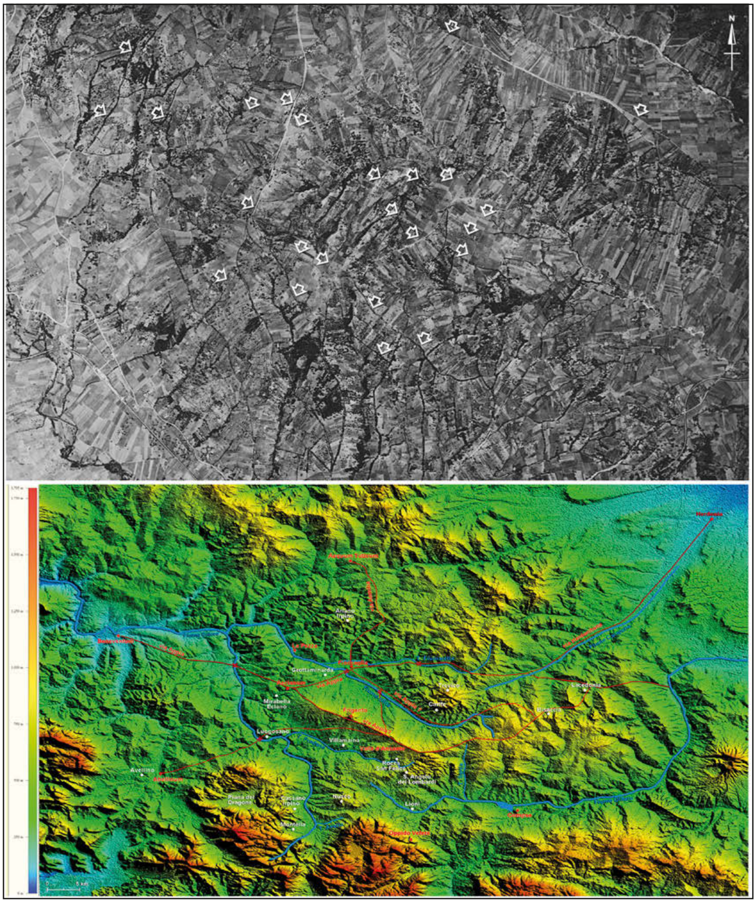

Fig. 4 – The territory of Irpinia (case study 2) in DEM (A) and historical aerial photograph (B) analised by the Archaeological Mapping Lab of ISPC-CNR (Lecce).

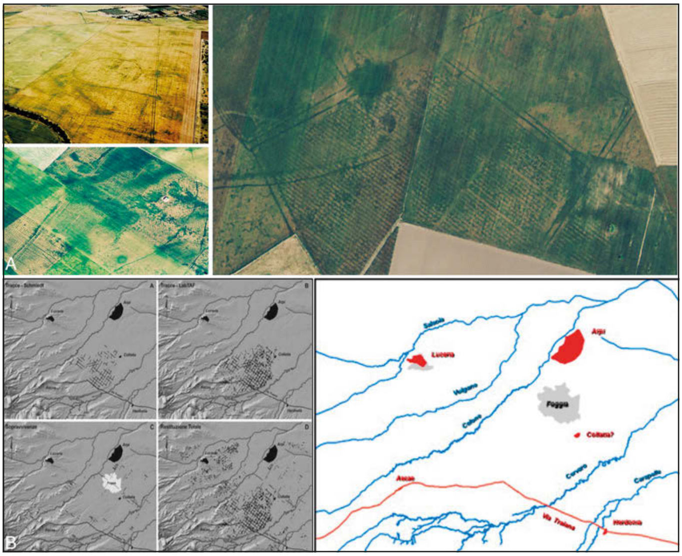

Fig. 5 – Northern Apulia (case study 3), centuriation systems as seen in and aerial photograph (A) and DEM (B) analised by the Laboratorio di Topografia Antica e Fotogrammetria LABTAF (Lecce).

division has been identified, which is coherent with the local hydrographic system (Fig. 5). On the basis of the gromatic texts (Lib. Col. I, 210, 8-9 L) it dates back to the land assignments made in the Graccan age in the *ager Aecanus* (Fig. 2B). The research carried out over the years has been a *unicum* in the field of centuriation studies for the use of aerial imagery as the main survey tool. The first evidence was identified by R. Bradford (1949); the research was resumed by G. Jones (1980) who made an overall reconstruction of the Tavoliere centuriation systems. G. Schmiedt (1985) reconstructed the module and orientation of the grid. More recent studies have significantly expanded its extension and recognized unitary meta-territorial planning, which included in a single cadastre the territory of more communities also with different status, the *ager Arpanus* and the *ager Collatinus* (Ceraudo, Ferrari 2010). The choice of this case study is due to some essential factors: at a time yet to be defined, this network went out of use; nevertheless, it is still well preserved and visible thanks to the exceptional number of cropmarks (roads, ditches) which constitute reliable *limites* of the grid (the ideal case for instructing the software to identify similar patterns in other geographical contexts). Above all, within almost every *centuria*, it is possible to recognize ancient cultivation trenches and pits.

V.F.

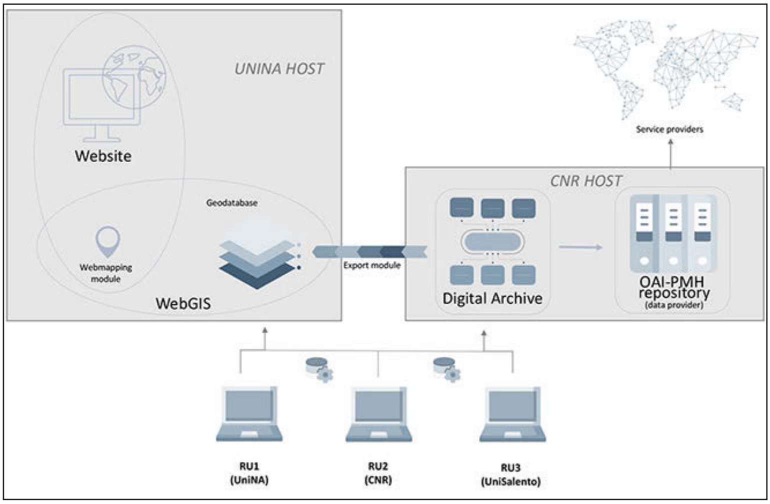

Fig. 6 – Components of the In.Res.Agri project's IT platform, the Digital_Groma.

4. Methods

4.1 *Digital_Groma: an open IT platform for heterogeneous data integration*

The systematic collection, integration, and exposure of the variety of data sources taken into consideration will be managed in a dedicated IT infrastructure, called Digital_Groma (Fig. 6). This will consist of three related modules: an archive for the collection and manipulation of legacy and new data on centuriation; a webGIS for data displaying and querying; a repository and APIs for data exposure in interoperable formats.

The digital archive will include a relational database with a user interface for data entry and manipulation, with capabilities for automated data import from related projects. The aim is to store, describe, enrich, and integrate diverse resources, including archaeological findings, textual sources, and visual materials. The open access repository aligns with the project's vision of data FAIRness. Descriptive metadata will be exposed according to standards, facilitating data provision to Italian and European e-infrastructures for archaeology and digital cultural heritage (Richards *et al.* 2021; Caravale, Moscati, Rossi 2024), and will also be retrievable through dedicated APIs.

The webGIS will be fed with geospatial, chronological, and archaeological data from the archive for investigating and visualizing the relationship among contemporary landscape, Roman centuriated agro-ecosystem and geomorphology. It will feature thematic maps for analyzing environmental, administrative, and cultural aspects, as well as archaeological elements such as Roman settlements and routes. The webGIS platform will serve as the convergence point for diverse data sources, spanning from texts to satellite images, and including new data from field research. These data will be integrated based on their topographic and semantic significance. It is important to note that this integration process will be digital and automated, differing from traditional computer cartography and representing a practical experiment in deep mapping.

I.R.

4.2 *Remote sensing and pattern recognition*

For each case study, the methods and tools applied in previous research will be verified, accessing archives of aerial photographs. Images will be processed and new information on ancient land division axes or evidence of roads and ancient fields will be georeferenced. The dataset of remotely sensed images will be enriched through the acquisition of recent high-resolution optical satellite images (WorldView 3 and 4, etc.); they will be orthorectified and processed with the aim of identifying archaeological traces (Fig. 7). Also unmanned Aerial Vehicles (UAVs) will be used for areas with limited coverage or to capture detailed images (Campana 2018). Both the aerial photographs and the satellite images will be used for Machine Learning tests for the automatic detection of centuriated fields (Traviglia, Torsello 2017). In the need to process large image datasets in archaeology, the Object-Based Image Analysis (OBIA) approach will be adopted.

This method allows for a reduction in interpretative ambiguity and is applicable to various scales of study. The object-based analyses are sequential: 1) image segmentation allows adjacent pixels with similar characteristics to be grouped; 2) rule-based classification makes explicit the geometric and spectral properties, as well as the spatial and relational ones, required to match the mental model to identify significant geo-objects. Field surveys and drone-based proximal sensing will verify remote sensing data. Areas for these surveys will be selected based on the potential relevance of traces to ancient land division grids. Pollen analysis will also be conducted to identify agricultural indicators.

P.M.

5. Conclusions

Research on agrarian landscapes in transition highlights the strong interaction between human communities and their environment, being the most pervasive alteration of the Earth's environment for several thousand years. With hundreds of hectares of agricultural land going out of production every day, the diachronic knowledge on introduction, spread, abandonment and

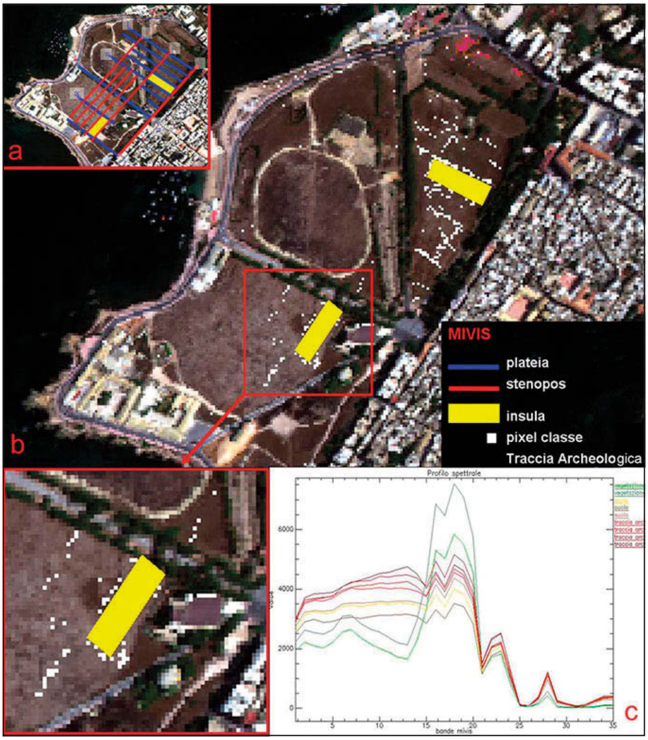

Fig. 7 – Examples of vectors obtained through machine learning application in a GIS platform.

change of agrarian landscapes represents one of the most important topics in the debates on field use policy. What happens when humans impose their spatial and temporal signatures on ecological regimes, and how does this manipulation affect the cultural landscape evolution? While each region has its own unique agricultural history, general patterns emerge which help make sense of how human actions have shaped the natural environment, and how rural landscapes changed, disappeared or have evolved through millennia. The endurance of Roman centuriation on landscapes for more than 2000 years might appear quite incredible. Unlike other types of land division, centuriation was a holistic enterprise with characteristics of incredible modernity that anticipated by two millennia our contemporary understanding of sustainable land design and management. The large dimension of the collected dataset on Roman agrarian landscapes of Campania and Puglia will allow to manage uniformly a whole complex of cultural assets regarding a vast region of

Southern Italy, that would otherwise be dispersed in different institutional repositories, with an immediate effect on research quality.

R.B., V.F., I.R.

Rodolfo Brancato
Dipartimento di Studi Umanistici
Università degli Studi di Napoli Federico II
rodolfo.brancato@unina.it

Veronica Ferrari
Dipartimento di Beni Culturali
Università del Salento
veronica.ferrari@unisalento.it

Immacolata Ditaranto, Pasquale Merola, Irene Rossi
Istituto di Scienze del Patrimonio Culturale - CNR
immacolata.ditaranto@cnr.it, pasquale.merola@cnr.it, irene.rossi@cnr.it

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ABSTRACT

The In.Res.Agri project aims to optimize the understanding of Roman agricultural landscapes in Southern Italy by integrating topographical, archaeological, environmental, and textual data within an innovative data-science platform. It focuses on examining the resilience of Roman agrarian landscapes, specifically through elements such as centuriation, route networks, and settlement patterns. The project employs both traditional survey methods and advanced technologies to recover, interpret, and manage archaeo-topographical data related to centuriation. Key methods include using Machine Learning for the automatic detection of centuriated fields, spatial analysis of both legacy and new data, and the use of annotated epigraphic and literary sources. All collected data will be implemented into the Digital_Groma platform, which will feature a digital archive and a webGIS for data display and querying; data will be exposed adhering to FAIR principles. In.Res.Agri will focus on regions in Campania (Vesuvian Area, Irpinia) and Puglia (Tavoliere), exploring the link between contemporary landscapes and Roman centuriated agro-ecosystems. This research is crucial for understanding the impact of environmental changes on Cultural Heritage, aligning with the priorities of the European Commission and UNESCO. The Digital_Groma platform will be accessible to researchers, tourists, and public institutions involved in archaeology, urban planning, and cultural heritage protection.